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A method for forecasting microwave propagation conditions below the 850 mb level is described and evaluated using radiosonde data in the eastern North Pacific Ocean. The method demonstrates good skill in assessing the existence of ducting or normal propagation conditions below the 850 mb level. Duct altitudes are not provided in the assessment, nor are the probabilities of occurrence. The categorical assessment is based on an 850 mb parameter derivable from model output fields, and can be used in ocean regions characterized by a marine

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inversion below the 850 mb level. The method does not seem useful in ocean regions at high latitudes or in those characterized by warm surface currents.

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REMARKS *(Continue on reverse)*

Enclosure (1) examines a method by means of which the existence or nonexistence of microwave ducts below the 850 mb level can be assessed and predicted. The 850 mb parameter used in the calculations can be derived from either the analysis fields or the forecast fields of the Fleet Numerical Oceanography Center's hemispherical model.

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         from model output fields, and can be used in ocean
         regions characterized by a marine inversion below the
         850 mb level. The method does not seem useful in ocean
         regions at high latitudes or in those characterized by
         warm surface currents. (Author)
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NAVENVPREDRSCHFAC TR 80-05

ASSESSMENT/FORECASTING OF ANOMALOUS MICROWAVE PROPAGATION IN THE TROPOSPHERE USING MODEL OUTPUT

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OCTOBER 1980

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CONTENTS

1. INTRODUCTION

    The Navy uses refractometer or radiosonde data to assess microwave* refractive conditions over the oceans. The refractometer procedure, which takes 2-3 hours, requires that aircraft tape recordings of refractometer data be recovered and then processed on a small programmable calculator. Radiosonde data can be processed as soon as they are received, in an hour or less.

    If radiosonde data at the task force location are not available, Fleet Numerical Oceanography Center (FLENUMOCEANCEN) in Monterey, California, can be requested to select the nearest radiosonde data available, compute the refractive structure, and send this information to the task force in coded graphical form via the message circuits; this procedure can take up to 3 hours.

    The disadvantages of these techniques are obvious; (1) radiosonde/refractometer data are needed, but not usually available; (2) time delays may invalidate assessments due to changes in ships' positions; (3) no forecast capability is provided; and (4) unrepresentative soundings may be used. The single advantage is that assessments based on refractometer or radiosonde data provide information on ducts' altitudes and strengths.

    This report examines a method by which the existence/non-existence of microwave ducts below the 850 mb level can be assessed and predicted. The method uses an 850 mb parameter which is derivable from either the analysis fields or forecast fields of the FLENUMOCEANCEN hemispherical model. This method is advantageous because it can be used for forecasting occurrence of elevated ducts and any naval ship can receive the information. The forecast of ducting would use FLENUMOCEANCEN forecast fields and therefore the skill of the forecast would be less--exactly how much is yet to be determined.

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    *Generally 0.01-100 cm wavelengths.

The method evolved from work of Gjessing and Moene (1967) in which an 850 mb parameter, ΔN, was correlated to the received signal data of an L-band radar and a 1-GHz radio link. By using an empirically determined threshold value for ΔN, the investigators were able to forecast the occurrence of anomalous propagation with an 80% accuracy.

This present method uses a similar 850 mb predictor parameter and shows very good correlation to the existence of microwave ducts below the 850 mb level. Radiosonde data from an ocean region off the U.S. west coast for the period 1960-65 were analyzed for ducts below the 850 mb level. The predictor parameter, Δe, was calculated for each of the radiosonde observations using 850 mb data, and a file was compiled with these data. Discriminant analyses was used to find the critical value of Δe, and this critical Δe was used to generate contingency tables and skill scores.

This study is a follow-on to work reported in Sweet, 1980, NAVENVPREDRSCHFAC TR 80-01, which used Gjessing's and Moene's ΔN parameter and considered three classes of refractive conditions based on an N gradient criteria: (1) ducts, $\frac{dN}{dz} < - .157$ N/km; (2) ducts and superrefraction, $\frac{dN}{dz} < - .10$ N/km; and (3) normal, $\frac{dN}{dz} > - .10$ N/km. TR 80-01 examined only data from zone 2 of the five geographical zones of data established for the EASTPAC area. The critical value of ΔN in TR 80-01 was chosen by otpimizing Heidke skill scores.

In this present report the classification functions are solved to find the critical Δe. Two classes of refractive conditions, ducting and normal, are considered; a third class considered in TR 80-01, ducting and superrefraction, was not included here since ducting conditions are believed to be more important than superrefraction (which to some extent is defined by agreement rather than by physics). The EASTPAC geographical zones defined for this study, and the numbers of radiosonde soundings that contributed data to the analysis, are shown in Figure 1.
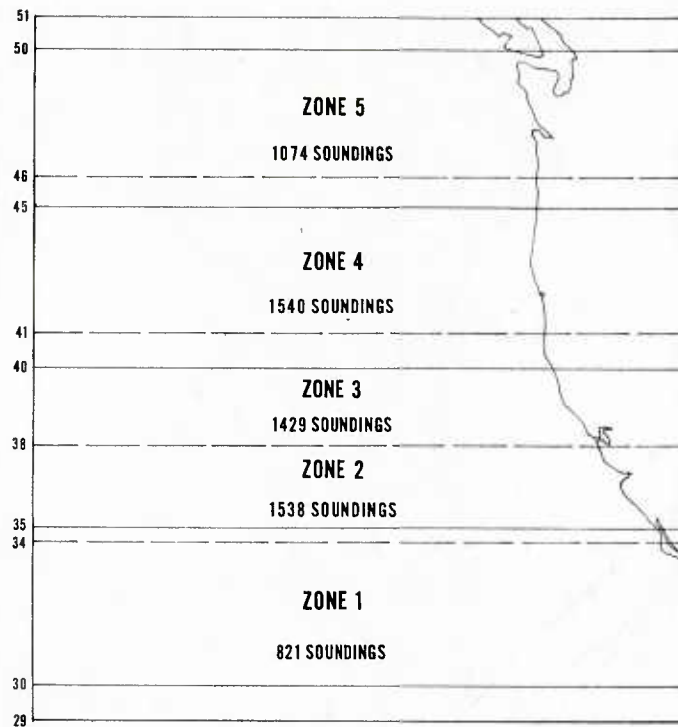
Figure 1. Geographical zones, and numbers
of soundings from each, that contributed
data to this study.

2. PHYSICAL RATIONALE FOR Δe METHOD AND DATA

Over a cool ocean surface, which provides a water vapor source
as well as a heat sink (regions of upwelling offshore of continents,
for example), a temperature inversion usually occurs. Water
vapor trapped within the marine layer by this temperature inver-
sion normally causes microwave ducting conditions. Dry air aloft,
at the 850 mb level, for example, would signify a temperature
inversion somewhere below that level, since synoptic conditions
which cause inversions are usually anticyclonic with accompanying
subsidence. In the region examined in this study, the inversion
heights were generally below the 850 mb level (~ 1500 m) as shown
in Figure 2.

A parameter that measures the dryness of the air aloft and
is calculated at a level above the inversions would then indicate
the likelihood of ducting below. Gjessing and Moene used a
parameter ΔN, calculated at the 850 mb level, which indicates the
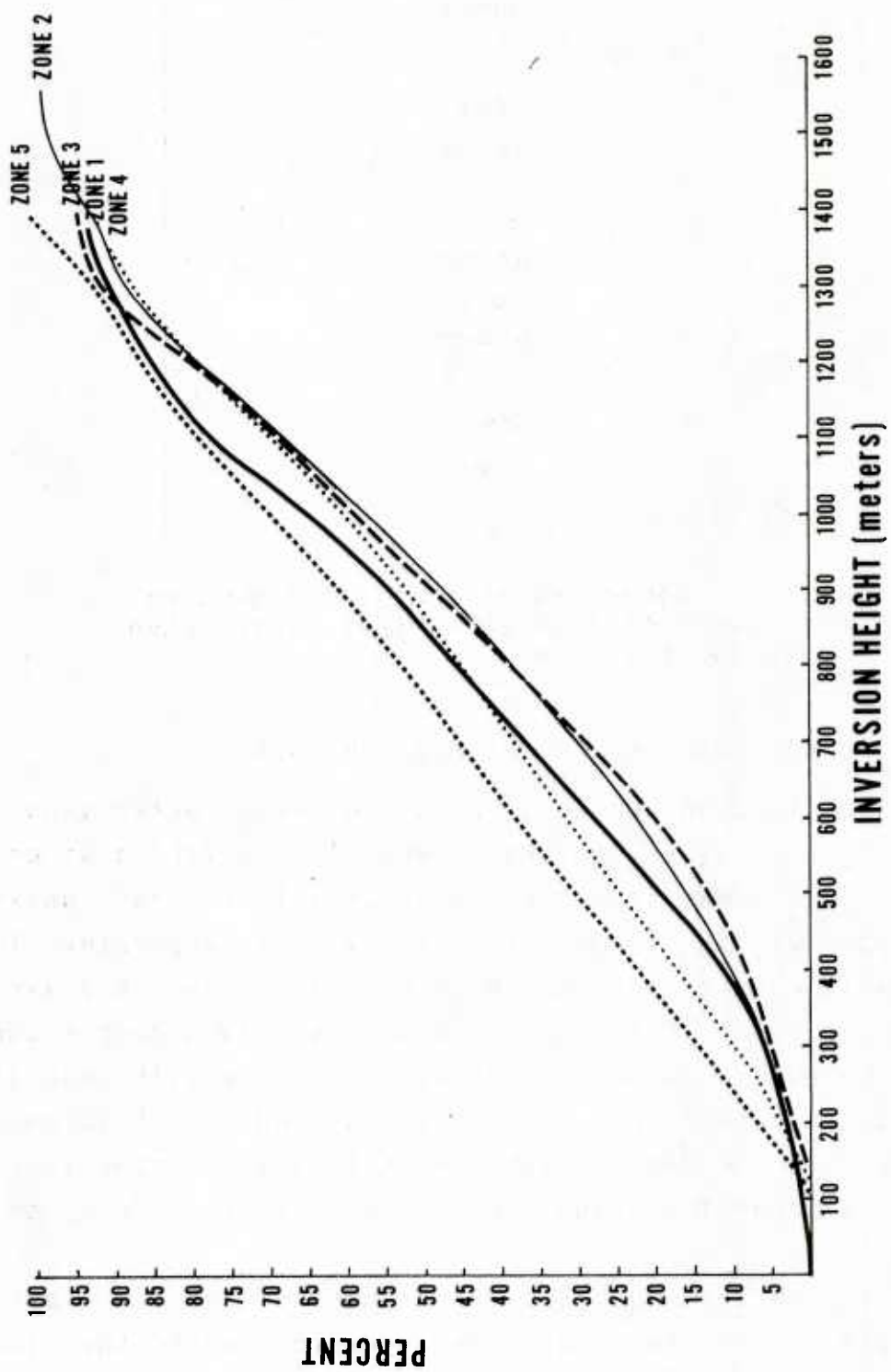dryness of the air using the wet term of the refractivity equation

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Figure 2. Cumulative distributions of inversion heights (m).

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$$N = N_W(Ta) - N_W(Td) \tag{1}$$

where

$$N_W(T) = Be(T)/T^2$$

and

$$Ta = \text{air temperature}$$
$$Td = \text{dew point temperature}$$
$$B = 3.73 \times 10^5$$
$$e(T) = \text{water vapor pressure at temperature T.}$$

This parameter measures the dryness of the air aloft, since

$$\Delta N = B[\frac{e(Ta)}{Ta^2} - \frac{e(Ta)}{Ta^2} - \frac{e(Td)}{Td^2}] \simeq \frac{B\Delta e}{Ta^2} \tag{2}$$

where

$$\Delta e = e(Ta) - e(Td) \tag{3}$$

For normal 850 mb temperature and dew points, the approximation in Eq. (2) is in error by no more than 10-15%. The linear correlation between ΔN and Δe, using actual radiosonde data, is better than 0.999. Thus Δe can and will be used in this present analysis to classify ducting conditions.

Gjessing and Moene (1967) used a critical value of ΔN equal to 15N units; a ΔN above 15N was assessed as ducting. The critical ΔN was chosen by inspecting received signal data from L-band radar and relating signal strength to ΔN values. The critical value was applied to three years of radar data obtained off the coast of southern Norway. The linear correlation coefficient between signal intensity and ΔN values was 0.76, and the total correct for 36 hr forecasts was about 80%.

With Gjessing and Moene's work as a guide, the pilot study reported in TR 80-01 (Sweet, 1980) used a sample of radiosonde data from the EASTPAC picket ship data to examine the skill of the ΔN predictor. The results obtained in this sample analysis

for one geographical zone were sufficiently encouraging to warrant analysis of the remaining picket ship data for all five EASTPAC zones, as reported herein; this study, at present however, uses the Δe parameter in place of the Gjessing and Moene ΔN.

The anticipated use of the Δe method is in assessing and forecasting ducting and normal propagation conditions based on FLENUMOCEANCEN analysis and forecast fields. Such uniform distribution of forecasts is not possible otherwise.

2.1 Limitations of the Δe Method

The forecasts/assessments of propagation conditions using the Δe method are limited to the vertical region below the 850 mb level. The method does not specify the expected altitudes of ducts, or whether there is more than one duct.

Ideally, forecasts developed by this Δe method would be issued as probabilities of ducting. For ocean areas where radiosonde data are available, this is possible and future efforts could be made to compile such information. Most ocean areas have sparse radiosonde coverage, however, and to extrapolate available data to such regions is risky, although some of this risk can be removed by careful synoptic comparisons between regions. In regions where ducting occurrences are relatively infrequent, ducting forecasts have a much lower confidence level since overforecasting is the rule. Forecasts of normal conditions (since this condition is more prevalent) will be more accurate and thus have higher confidence values.

2.2 Data

Only radiosonde data were used in this analysis of the Δe method, in contrast to the work of Gjessing and Moene which used received signal data. The radiosonde is a useful instrument for determining upper air characteristics, but its near-surface (0-100 m) accuracy can be misleading. Helvey (1979), reported that surface temperature biases produced inaccurate relative humidity profiles near the surface; surface duct statistics obtained from radiosonde data are biased toward greater percentages of surface ducts. Some of these biases were removed in this

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study (see following section), but no attempt was made to correct the lag inherent in radiosonde data.

Radiosondes were launched from radar picket ships stationed about 200 n mi off the west coast of the U.S. Variations in the positions of the ships while they were on station caused considerable scatter in the geographical locations of soundings. The 6402 soundings used in this study were divided among the five zones shown earlier in Figure 1. The determination of the boundaries of these zones was guided by a need to (1) include the intended station locations, (2) minimize the number of reports on the lines of demarcation, (3) minimize the movement of ships accross the selected lines, and (4) avoid concentration of data near the boundaries.

Data were obtained from the National Climatic Center, Asheville, NC, in two forms: WBAN-31A adiabatic charts, and CDF-645 and CDF-505 computer tapes. The adiabatic charts were processed by a digitizer whose card output was then input to a CDC-6500 computer for processing. Quality control checks removed all soundings with coding errors and made reasonable corrections to obvious bad data points.

3. ANALYSIS PROCEDURE

3.1 Data Editing

The soundings were checked for coding errors, missing levels, erroneous readings of relative humidity, temperature, pressure and height, and surface superadiabatic layers. If the latter layers were found, the lapse rate was adjusted to adiabatic (dew point lapse rates were unchanged).

The superadiabatic lapse rates were adjusted for two reasons: (1) there is no reasonable physical process over the oceans, whereby surface superadiabatic lapse rates can be maintained under clear skies; and (2) the time of occurrence of 2500 superadiabatic surface lapse rates was biased, heavily favoring the afternoon soundings by a margin of 59% to 41%. (An afternoon sounding is affected by biased surface temperatures due to insolation

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heating of the ship and subsequent heating of the radiosonde. Some soundings reported autoconvective layers at the surface; this phenomenon can be expected within a few meters of a desert floor, but clearly is not likely over the ocean.)

After editing, the soundings were examined for ducts between the surface and 850 mb and the value of Δe at 850 mb was calculated. A file of this information was then used as input data to the P7M group multiple discriminant analysis program of the University of California at Los Angeles BMDP statistical package (Dixon, 1977).

3.2   Critical Δe Value

The P7M program uses a stepwise procedure for multiple predictor variables to compute linear classification functions. For a single predictor, the classification functions are a pair of linear equations relating the predictor to the classification groups.

As an illustration of this relationship, let a, b, c, and d be the constants determined by the discriminant analysis program, and let X, Y, be real valued numbers. Then,

$$X = a \Delta e + b \quad \text{(ducting)}$$

$$Y = c \Delta e + d \quad \text{(normal)}$$

If Δe is the 850 mb value of Δe, then $X \geq Y$ assesses ducting and $Y > X$ assesses normal conditions. This procedure involves several computations; a simpler method in the case of simple discrimination is to classify according to a critical value of Δe, whose value is found by equating $X = Y$ and solving for Δe:

$$\Delta e_c = \frac{b-d}{c-a} \; .$$

If Δe_c is exceeded, ducting is assessed; and if it is not, normal conditions are assessed.

The pilot study (Sweet, 1980; TR 80-01) which used only the data in zone 2 of Figure 1, found the critical value of the predictor, actually ΔN, by optimizing the Heidke skill scores. This

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method was found to be inadequate for the present study because of the variation in Δe_c among independent data samples taken from the same zone. The variation resulted from the ambiguity of the optimum value of Δe_c. Figure 3 shows that the maximum in the skill versus Δe curve is not distinct; in fact, several near maximum occur, leaving the selection of one true optimum value of Δe unclear.
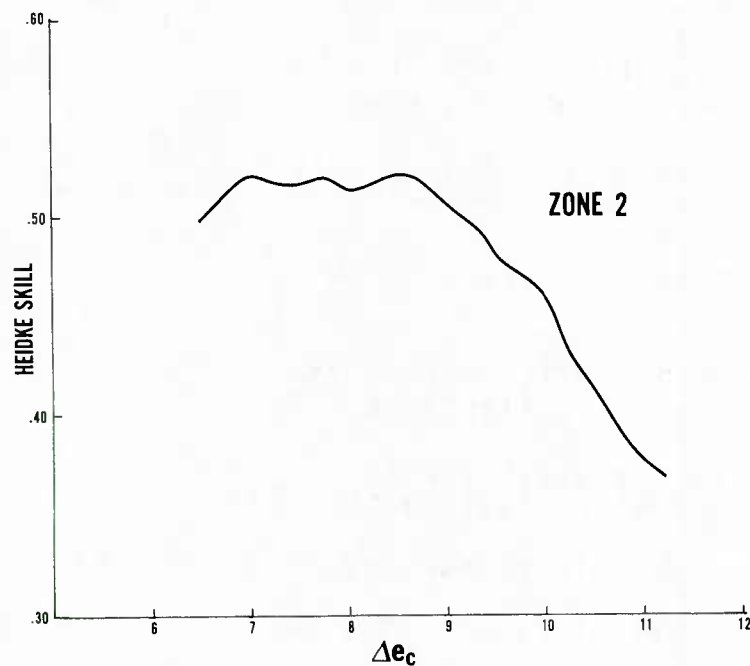

Figure 3. Heidke skill scores versus Δe_c, zone 2.

3.3 Analysis Procedure

Contingency tables were computed from both dependent and independent data, using the Δe_c value for each zone. Tables 1-5 are for the dependent data sample (50% of the total available soundings in each zone).

The columns are the observed (actual) groupings and the rows are the classified groups. For example, in Table 1, of the 197 total soundings classified as ducts, 151 soundings were observed to be ducting and were classified correctly. The 46 soundings observed to be normal, but classified as ducting, were incorrectly

Table 1

Zone 1

		Observed		
		Ducts	Normal	Total
Assessed	Ducts	151	46	197
	Normal	44	128	172
	Total	195	174	369

Total % correct - 76%

Duct prefigurance - 76%
Normal prefigurance - 75%

Duct postagreement - 77%
Normal postagreement - 74%

Climatology (ducting below 850 mb) - .53

Critical Δe = 10.4 mb

Heidke skill - .51

Table 2

Zone 2

		Observed		
		Ducts	Normal	Total
Assessed	Ducts	208	113	321
	Normal	55	375	430
	Total	263	488	751

Total % correct - 78%

Duct prefigurance   - 64%
Normal prefigurance - 88%

Duct postagreement   - 79%
Normal postagreement - 77%

Climatology (ducts) - .37

Critical Δe = 7.8 mb

Heidke skill = .53

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Table 3

Zone 3

		Observed		
		Ducts	Normal	Total
Assessed	Ducts	118	95	213
	Normal	36	449	485
	Total	154	544	698

Total percent correct - 81%

Duct prefigurance   - 55%
Normal prefigurance - 93%

Duct postagreement   - 76%
Normal postagreement - 83%

Climatology (ducts) - .22

Critical Δe - 6.3 mb

Heidke skill - .52

Table 4

Zone 4

		Observed		
		Ducts	Normal	Total
Assessed	Ducts	77	119	196
	Normal	29	516	545
	Total	106	635	741

Total percent correct - 80%

Duct prefigurance   - 39%
Normal prefigurance - 95%

Duct postagreement   - 72%
Normal postagreement - 82%

Climatology - .15

Critical Δe - 5.3 mb

Heidkie skill - .40

Table 5

Zone 5

		Observed		
		Ducts	Normal	Total
Assessed	Ducts	41	68	109
	Normal	21	376	397
	Total	62	444	506

Total percent correct - 82%

Duct prefigurance   - 37%
Normal prefigurance - 95%

Duct postagreement   - 66%
Normal postagreement - 85%

Climatology - .12

Critical Δe - 5.1 mb

Heidke skill - .38

classified. The sum of the diagonal elements in Table 1 is the number of total correct classification. The total percentage correct is this sum divided by the total number of soundings used, 369. This same design is applied to the remaining tables.

The accuracy and the false alarm rate of the procedure can be examined using two percentages: prefigurance and postagreement. Duct prefigurance is the percentage of the number of correct duct assessments. Postagreement is the percentage of actual ducts correctly assessed. The sample space of prefigurance is the total number of ducts assessed; the sample space of postagreement is the total number of ducts.

The critical value of Δe could have been chosen by maximizing either of these percentages. For example, the optimum Δe_c could have been selected by maximizing the duct prefigurance, thereby reducing the false alarm rate. Maximizing postagreement would increase the accuracy of the procedure, i.e., increase the number of ducts correctly assessed. The operational aspects of pre-figurance and postagreement and the difference in emphasis depending on which of these is stressed, are discussed below.

3.4   Prefigurance and Postagreement

A low duct prefigurance percentage indicates that a large percentage of assessed ducts were actually normal conditions; this is a high false alarm rate. The nature of the intended opera-tion would determine whether a high false alarm rate is less objectionable than a lower rate that misses many ducts altogether.

In actual operations, the forecast often generates the action: ships' tactics are planned, particular ordnance is loaded, electro-magnetic emission operations are chosen based on the "forecast." Once a decision is made and a tactic is chosen, the outcome of such decisions depends on the correctness of the "forecast" used to make that decision. Prefigurance, therefore becomes the more important factor under the assumptions just stated.

Postagreement is meaningful mainly in hindsight. If a commander wanted to assess an operation during which the accuracies of several different forecast procedures were compared, for exam-ple, then the postagreement percentages would be useful.

A concern only with postagreement, however, could lead to choice of a procedure that forecasts ducting conditions 100% of the time, since every ducting day that occurred would then have been predicted. Conversely, those days that actually had normal propagation conditions would have been forecasted as ducting a 0% normal postagreement. If cost/loss factors allow such percentages to be acceptable, then such a procedure might well be chosen as the optimum.

Without cost/loss factors and other pertinent operational considerations, the only reasonable choice is to emphasize the forecast accuracy, prefigurance. (The assumption here is that the method would be applied to 850 mb forecast fields, producing a direct forecast.)

4. DISCUSSION OF RESULTS

4.1 Critical Δe - Discriminant Analysis

The table given below shows the zone-to-zone variation of the critical Δe and the variation between independent data sets. The two data sets are simply complimentary sets, the first one chosen by a reproducible random process. The stability of Δe_c is indicated by the small variations of Δe_c between the dependent (the first data set chosen) and the independent data. The variation of the zonal Δe_c values follows the climatological variation of duct occurrence extremely closely: the linear correlation coefficients are .996 and .993 for independent and dependent samples, respectively. The larger values of Δe_c are related to the regions with more frequent ducting. The variations of the skill scores between data sets are less than 0.05 (see Sweet, 1980, TR 80-0, for an explanation of Heidke skill scores). The small variation is an indicator that the selection criterion is a good one.

Zone No.	Dep.	Δe_c (mbs) Indep.	Skill	Relative Frequency
1	10.4	10.5	.51 - .53	.53
2	7.8	8.0	.53 - .51	.37
3	6.3	6.1	.52 - .47	.22
4	5.6	5.3	.40 - .40	.15
5	5.1	5.2	.38 - .36	.12

There is an unusual linear relationship between Δe_c and the relative frequency of ducting. The following table is helpful in examining possible reasons for this relationship:

Zone No.	Surface/ Total	Ratios Elevated/ Total	Surface/ Elevated	Percent Correctly Assessed as Normal Surface	Elevated
1	.047	.485	.098	33	9
2	.060	.302	.200	41	7
3	.046	.185	.251	23	9
4	.033	.122	.270	41	10
5	.031	.078	.400	28	8

The elevated-to-total duct ratio decreases with climatology, whereas the surface-to-total duct ratio does not. The climatology then is correlated to the number of elevated ducts. This correlation may be explained by the relative dryness of the air at the 850 mb level needed to indicate ducting due to the marine inversion. The generally cooler temperature of northern latitudes, compared to more southern latitudes, would cause the specific humidity to be less; therefore, the difference between saturation and ambient vapor pressure values would, on the average, be smaller. This smaller mean value of Δe would nevertheless still be an indicator of an inversion below and of the accompanying ducting conditions. The lack of correlation between the relative frequency of surface ducts and the Δe_c implies the lack of a real physical link between these two events.

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Another possible meteorological factor is the height of
the temperature inversion -- a higher mean inversion height would
probably correlate with a smaller Δe_c. The cumulative height
distribution for each of the five zones, as shown in Figure 2,
are very similar: the 50% point varies from 750 m for zone 5 to
925 m for zone 3, but at the 75% point the variation is only 75 m.
The distributions do not show any systematic variation from
zone 1 to zone 5; the variation of inversion heights with zone
therefore is not a significant factor, and has no effect here
on the critical Δe interzonal variations.

4.2 Contingency Tables

Contingency tables, developed by applying the critical Δe
to the independent data set and analyzing by discriminant analy-
sis, show a gradual increase in the total percent correct with
increasing latitutde (refer to Tables 1-5). The reason for this
increase in percent correct is the gain in reliability of
assessing the normal conditions, even though the duct assessment
becomes less reliable. The prefigurance percentages for ducting
and normal propagation by zones (hence by climatology) are shown
in Figure 4. In zone 1 the climatology for ducting is essentially
the same as for normal conditions; the prefigurance percentages
of 76% and 75% respectively reflect the nearly equal occurrence
frequencies.

The variation in postagreement of ducting and normal condi-
tions follow less spectacularly the same general zonal trends as
the prefigurance percentages. In zone 5 the difference between
ducting and normal postagreement (Figure 5) is less than 20%,
compared to almost 60% for zone 5 prefigurance. Ducting is rela-
tively infrequent for zone 5, and hence difficult to assess.
Over-assessing (over-forecasting) causes the accompanying low
prefigurance, but the ducting postagreement is relatively high
because of this overassessing.

4.3 Critical Δe - Heidke Skill Score

Choosing the critical Δe with an intent to optimize the
skill score causes greater variation in Δe_c between samples in
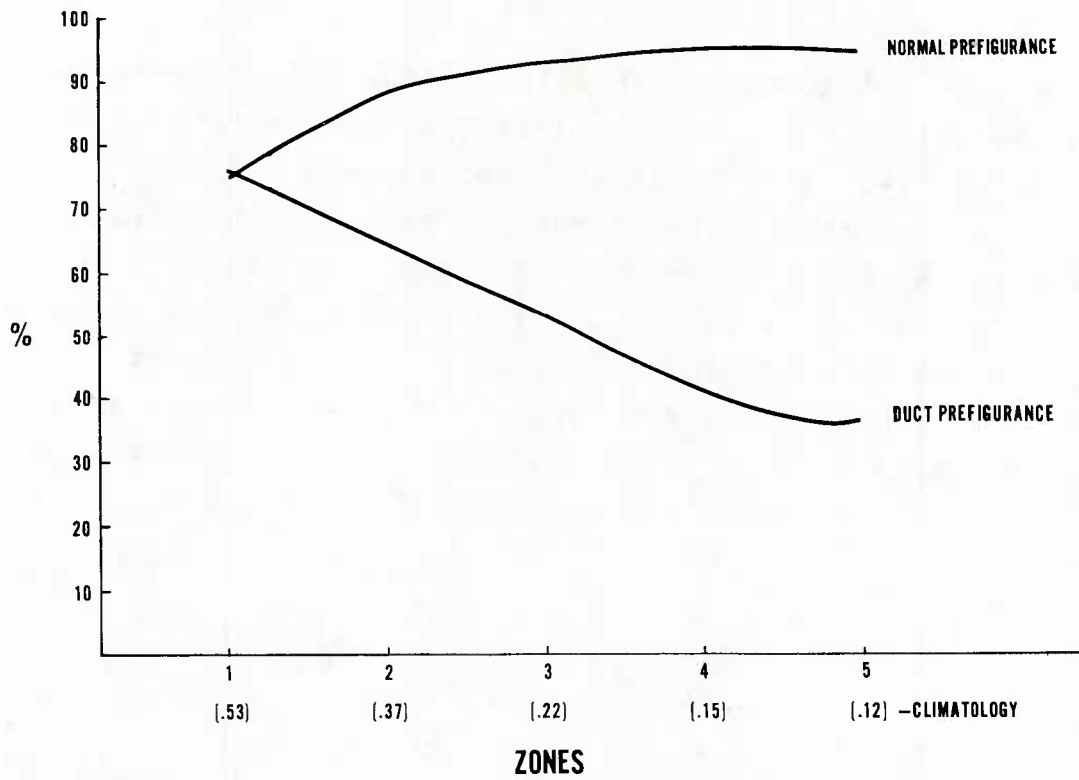
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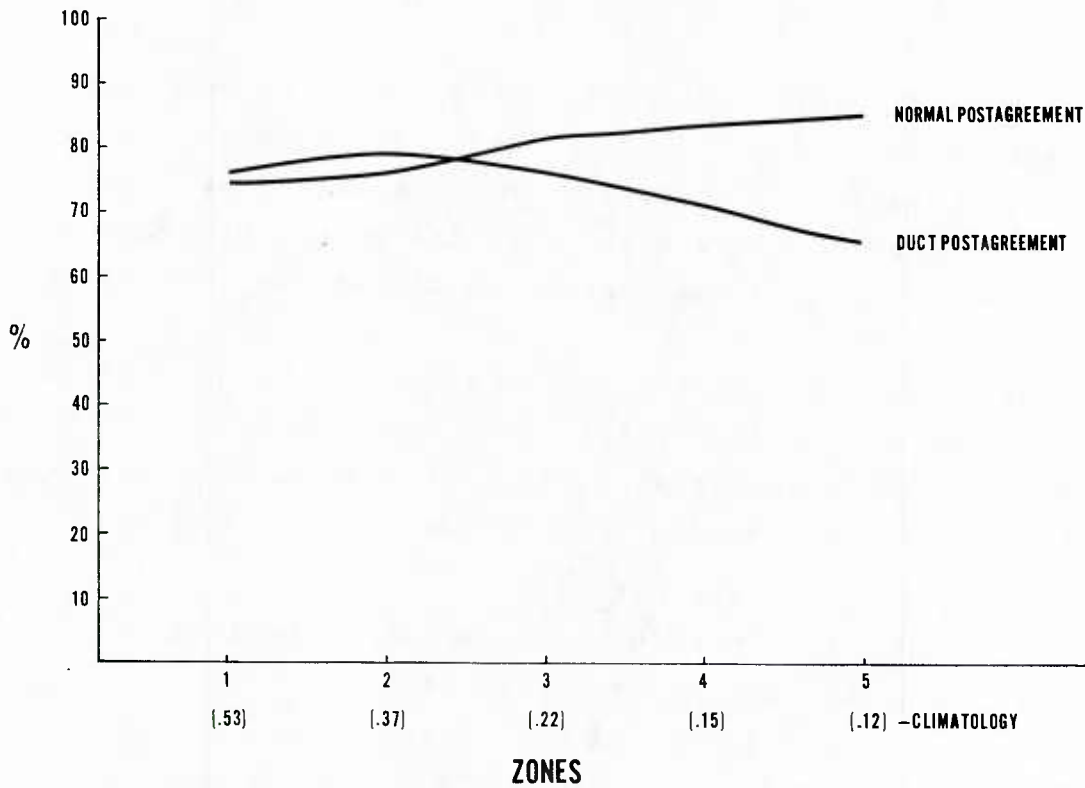Figure 4. Prefigurance percentages for ducting and normal propagation.

Figure 5. Postagreement percentages for ducting and normal propagation.

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the same zone. This variation results from the criteria for the Δe_c selection: Δe_c is the first "maximum" on the skill versus Δe_c curve. This first apparent maximum may indeed be only a local maximum, as was shown in Figure 3; the relative flatness of the maximum region of the curve in Figure 3 indicates that this method of selecting Δe_c is not stable. The variation in Δe_c for two samples of zone 3 (see Para. 4.4) exemplify that instability; sample sizes are large enough to preclude an unrepresentative sample with at least a 95% confidence. The following table gives the Δe_c found by Heidke skill scores, and the skill values:

Zone No.	Δe_c Dep.	Indep.	Skill	Relative Frequency
1	9.0	8.6	.51 - .56	.53
2	7.8	7.0	.52 - .51	.37
3	7.0	8.0	.53 - .54	.22
4	7.0	7.6	.42 - .38	.15
5	6.8	7.6	.36 - .36	.2

The zonal variation of Δe_c varies with the relative frequency of duct occurrence in a nearly linear relationship. The linear correlation coefficient for the relation is a high 0.968. This high correlation substantiates the even higher correlation found previously, and reinforces the climatology versus Δe_c relationship.

The interzone variation of skill scores for the discriminant analysis and the maximum skill method are very similar. The intrazonal-sample dependent variations are of the same magnitude as found earlier, with the largest .05.

4.4 Critical Δe - Other Methods

There are other possible methods for selecting Δe_c, depending on the intended use of the assessment/forecast.

The plots of ducting and normal prefigurances and postagreement for zone 3 are shown in Figure 6. The curves for the total

percent correct, normal prefigurances and postagreement do not vary greatly with changing Δe_c. The ducting prefigurance steadily increases throughout the range of Δe_c plotted, and presumably would continue up to the point where the criteria were met by only a few soundings. Then the percentage may rapidly fluctuate as the Δe_c increases, because of a too-small sample size. This would occur well beyond the point of forecast distribution matching climatology. Therefore choosing an optimum Δe_c is not benefitted based on examination of such plots as Figure 6.
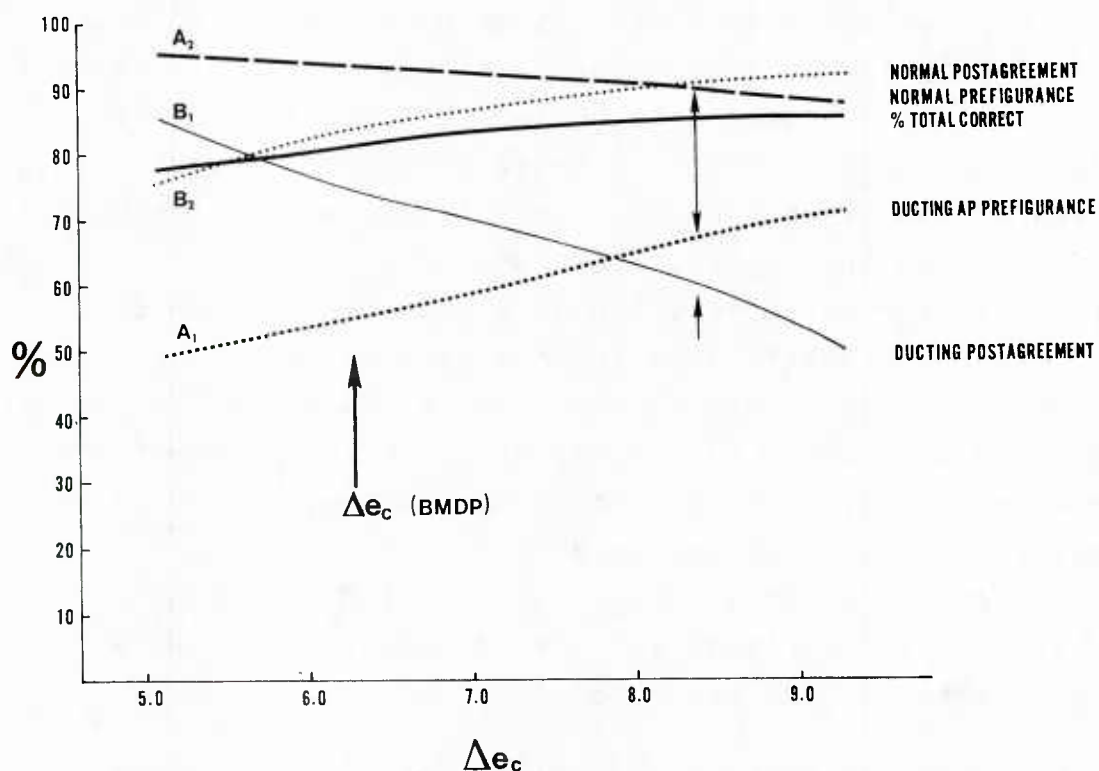

Figure 6. Plots of ducting and normal-propagation prefigurance and postagreement for geographical zone 3.

An upper limit of Δe_c could be set, however, at the point at which the ratio of ducting forecasts to total forecasts matches climatology (the number of predicted "ducting events" matches the numbers of observed "ducting events"). These values are given in the following table under climatology. The rightmost column gives the ranges of Δe_c for each zone, i.e., the difference between Δe_c chosen by discriminant analysis and by climatology.

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Zone No.	Δe_c Discriminant Analysis	Climatology	Range
1	10.4	10.4	0
2	7.8	8.7	.9
3	6.1	7.8	1.7
4	5.3	8.0	2.7
5	5.1	7.5	2.6

The values established by climatology minimize the false alarm rate for ducting. These ranges are useful for selecting the optimum Δe_c depending on the tactical application of the forecast. For example, if false alarms are to be minimized even at the expense of increased inaccuracy of the normal forecasts, then the upper value of the Δe_c range would be used. If the cost for not forecasting ducting when ducting occurred was of greatest significance (with a parallel desire not to over-forecast to an extreme), then the Δe_c found by discriminant analysis would be used. The range of Δe_c offers some flexibility that will enable the user to adjust the Δe_c based on experience gained in specific ocean regions.

The preferred value obviously is the Δe_c found from discriminant analysis. Flexibility is added through using a range of Δe_c limited at the upper boundary by climatology.

4.5 Characteristics of Soundings Incorrectly Classified

The Δe_c procedure is based on the assumption that if the air at 850 mb is very dry, and is over a body of water, a temperature inversion exists at some elevation between the surface and the 850 mb level. These temperature inversions produce water vapor gradients that usually are steep enough to cause microwave ducting. (The correlation between these two situations has been established at least for the North Sea and the eastern North Pacific.) Certain modifying factors of this relationship, however, should be noted.

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Some surface ducts, maybe most, apparently are not related to dry air at 850 mb. Figure 7 shows a sounding that indicates a temperature inversion above the 850 mb level, but the inversion does not appear to be related to the surface duct. The modified refractivity profile indicates a duct whenever the M values decrease with height. The reason for such ducts cannot be ascertained solely from radiosonde analysis; a synoptic analysis also must be performed.

Sometimes weak inversions that produce ducts occur below or near 500 m, while the air above the inversion is not dry enough to meet the Δe_c criteria. Figure 8 depicts such a case with a sounding that appears unusual in two areas: the dew point inversion between 100 and 300 m seems suspect, and the parallel drop-off of both temperature and dew point above 1500 m is similarly so. This sounding actually shows a slight surface duct up to about 80 m (slight decrease in M with height) with an elevated duct just below 500 m. The indications of either of these ducts may in fact be the result of radiosonde errors due to the instrument's ascension through stratus tops.

Surface ducts occasionally have the appearance of extremely thick evaporation ducts. Figure 9 shows a sounding with a surface duct over 200 m thick, with multiple, weak temperature inversions above 1000 m. A surface pressure of 1025 mb suggests that these inversions were caused by subsidence aloft. At the 850 mb level, the cool air temperature (4.0°C) causes the Δe value to be less than Δe_c, even though the temperature-dew point difference is a surprising 25.9°C.

The soundings in Figures 7, 8 and 9 illustrate cases that indicated ducting, but were classified as normal. Figure 10 shows a non-ducting M profile that was classified as ducting; a strong temperature inversion over a nearly 300 m vertical extent is depicted. The decrease in dew point temperature shown in Figure 10 was not steep enough to produce a duct, even though Δe was calculated to be 16.1 mb, well above the Δe_c. This large value was due primarily to the warm air temperature at 850 mb.
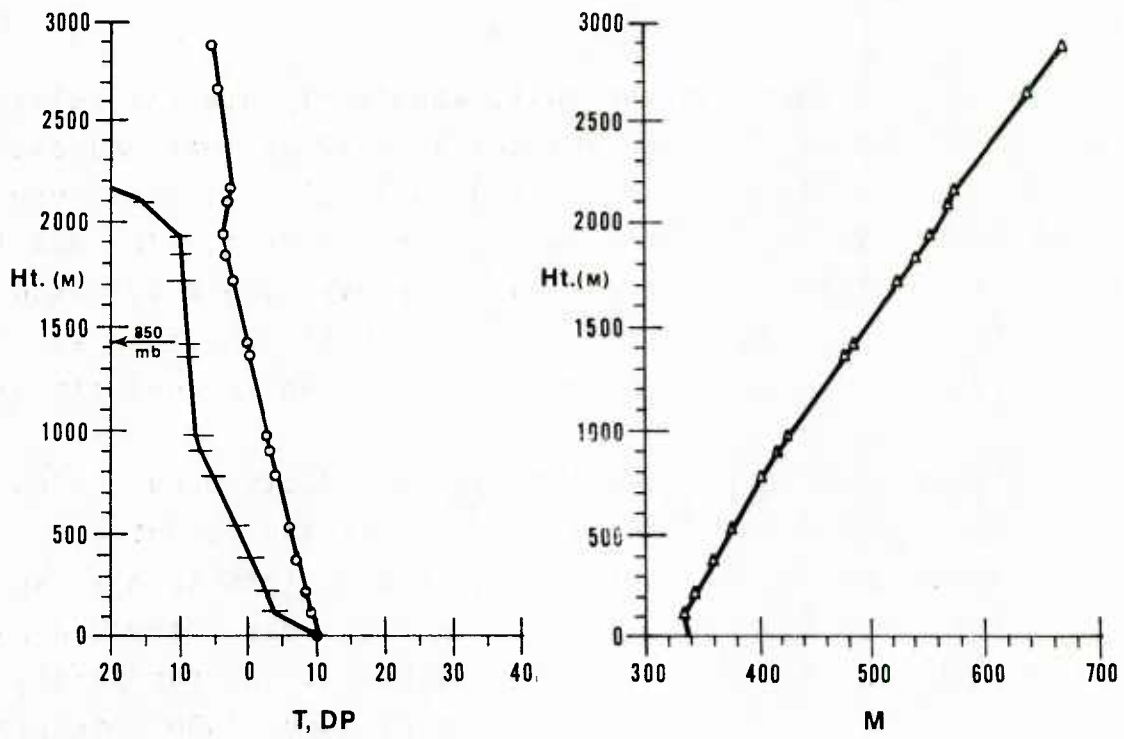
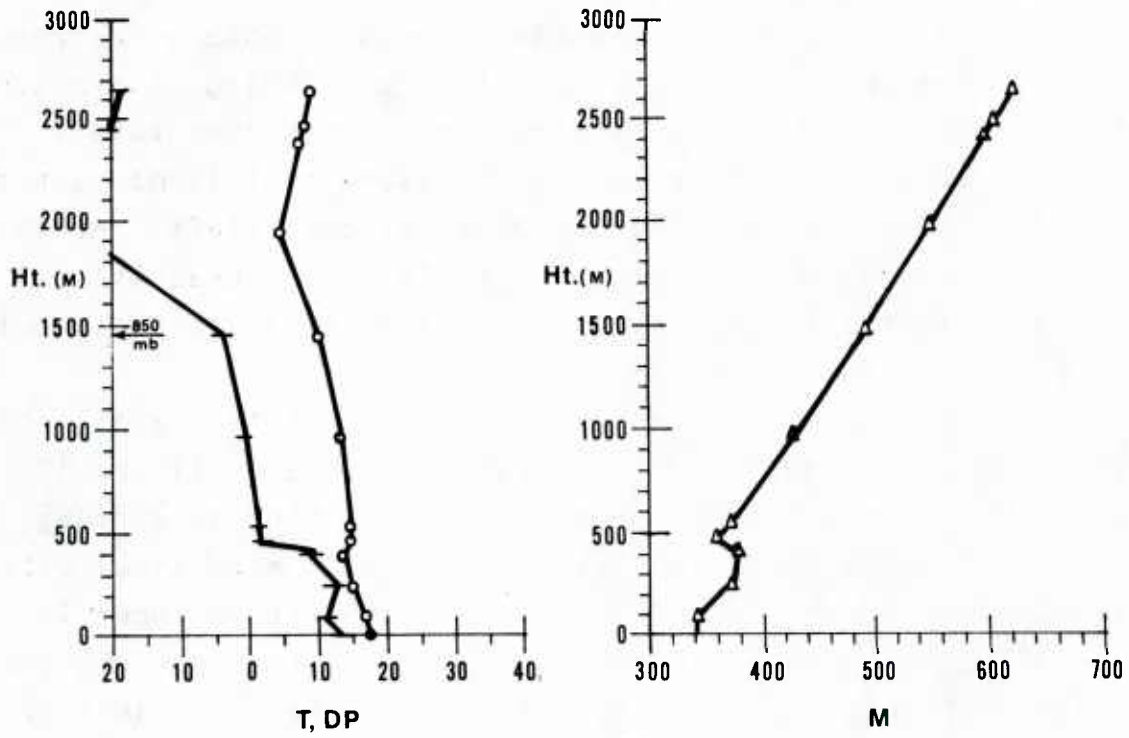Figure 7. Sounding with Δe = 2.8.

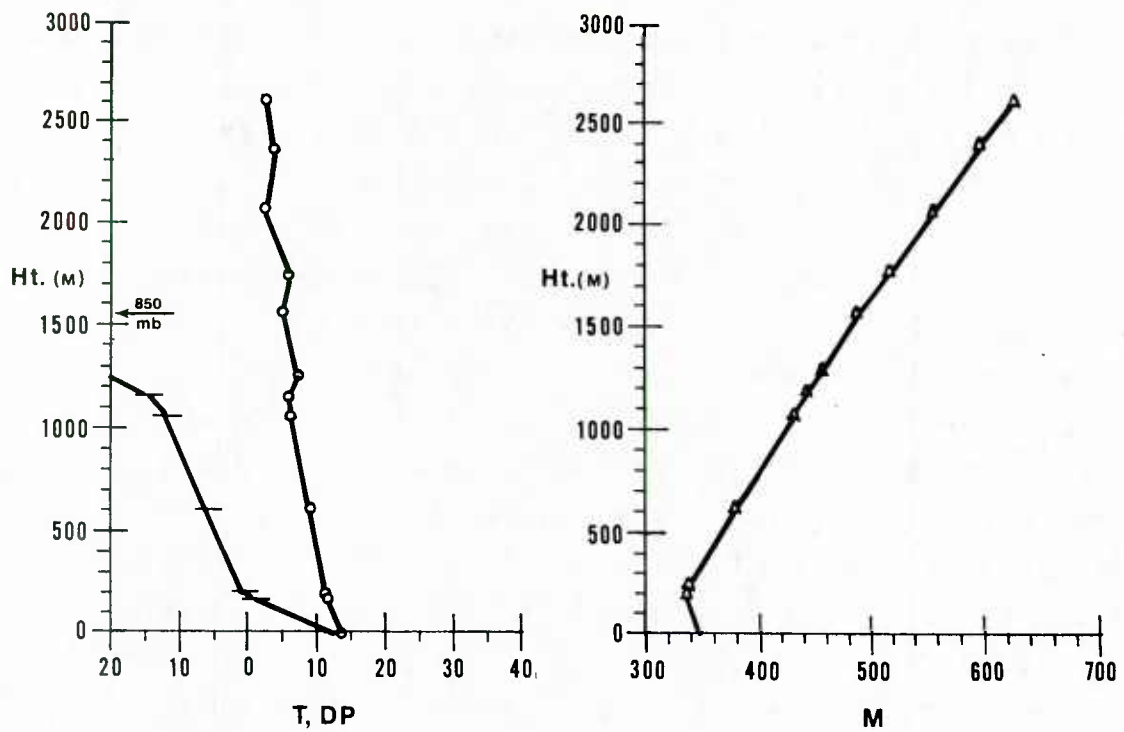Figure 8. Sounding with Δe = 7.7.

24
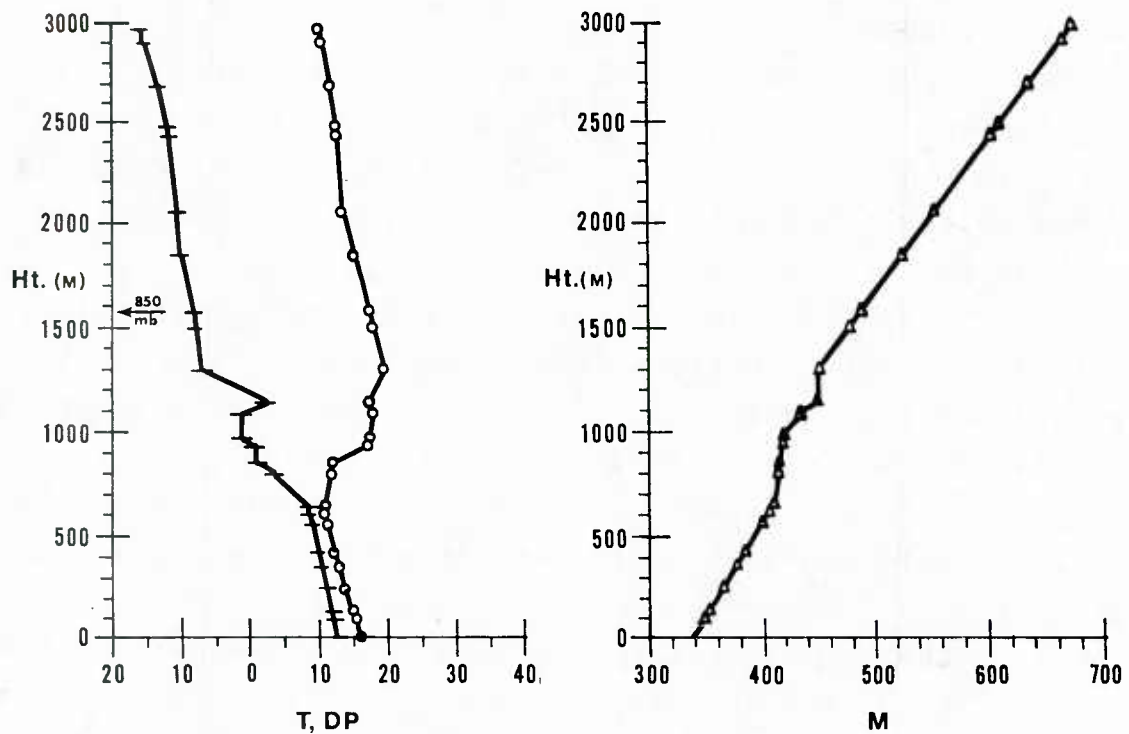
Figure 9. Sounding with $\Delta e = 7.1$.

Figure 10. Sounding with $\Delta e = 16.1$.

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Figure 11 illustrates a similar case: the air at 850 mb
is dry, but the dew point gradient is not strong enough to
produce ducting. Figure 11 shows an almost linear M profile
in which the temperature dew point difference slowly increases
with altitude. For zone 2 the value of Δe is above the critical
value, primarily because of the warm 850 mb temperature.

Figure 12 depicts a case in which an elevated duct results
from a very weak temperature inversion and an accompanying steep
dew point gradient. The value of Δe is not large enough to
classify the sounding as ducting because of an apparent dew point
increase in the region of 850 mb, an increase that could have
been caused by the radiosonde ascending through a layer of
cloud (the dew point does drop off just below a second small
temperature inversion).

The examples just discussed (Figures 7-12) were selected
to illustrate the various problems that can occur in incorrectly
classified soundings: some show weaknesses in basic assumptions,
while others demonstrate the results of weaknesses of radiosonde
data.

5.   FUTURE WORK

Recent work done by researchers at Pacific Missile Test Cen-
ter, Pt. Mugu, CA has shown that there is considerable skill to
be derived from an additional parameter that allows development
of probability statements about the vertical location of the
inversion duct (R. Helvey, private conversation). Future work
will combine this Δe discriminator with Helvey's "equivalent
altitude" parameter (Helvey, 1979); the combination will be
examined using the data set developed for this present report.

If this combination is found to have value, other ocean
areas characterized by cold currents with resulting marine layer
inversions will be examined to determine the universality of
the method.

After the validity and operational usefulness of the method
are established, the next logical step would be to examine care-
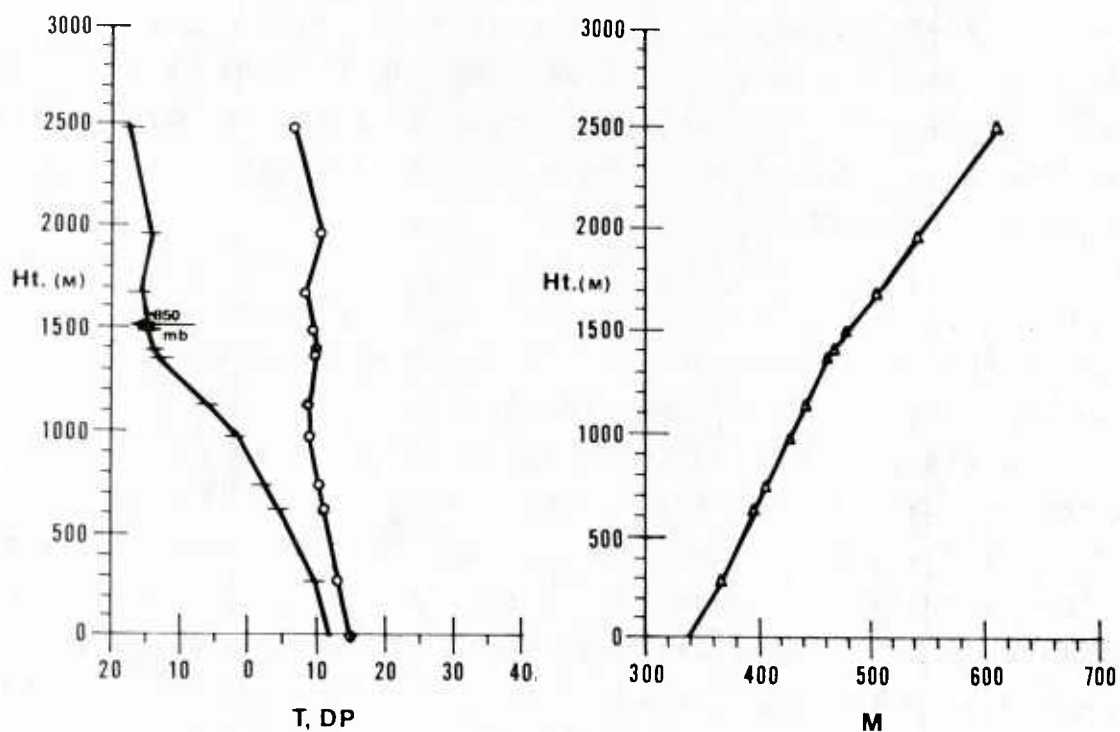fully the skill of the procedure under operational conditions

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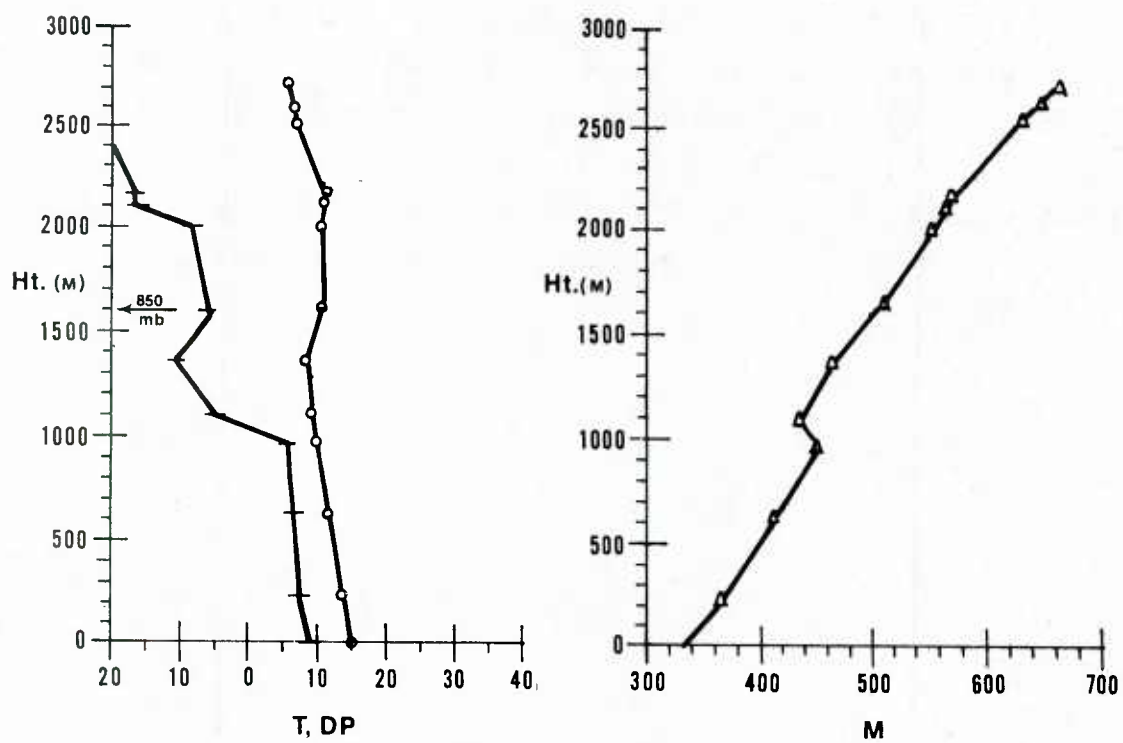
Figure 11. Sounding with Δe = 9.9.

Figure 12. Sounding with Δe = 8.1.

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using data fields from FNOC's forecast model to provide the input. The forecast of refractive conditions would be verified by using available radiosonde data nearest the time and location of the forecast. Given ample data, regional guidelines then could be established.

6.   SUMMARY

A method that assesses (and could forecast) the occurrence of ducting within 1500 m above the ocean has been described. The method was examined using radiosonde data from five latitutde zones of the eastern Pacific Ocean. The skill of the method was found to equal or exceed that of standard weather forecasts.

The parameter (Δe) used to assess/forecast ducting or normal conditions is calculated using only 850 mb level data. Therefore the method can be applied using FNOC 850 mb field output from the hemispherical model, thereby providing a forecast capability in open ocean regions void of radiosonde data.

The critical value of Δe used for the assessment/forecast is selected using discriminant analysis. The value of Δe_c shows a strong linear correlation to the relative frequency of ducting. This linear relationship results from the method skill in assessment/forecasting of elevated ducts, since their latitudinal variation of relative frequency accounts for all of the total latitudinal variation in critical Δe.

The variation of Δe_c for different samples of data within any zone is small, indicating good stability in the method of choosing Δe_c.

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Sweet, W., 1980: Anomalous microwave propagation assessment in the lower troposphere using a bulk meteorological parameter, NAVENVPREDRSCHFAC 80-01, Naval Environmental Prediction Research Facility, Monterey, CA 93940, 24 pp.

APPENDIX A

Comparison of Δe and $\Delta \theta$

Consider a parameter defined as the difference between the 850 mb level and the surface level potential temperature, $\Delta\theta = \theta 850 - \theta$surf. If this parameter is positive, then the air aloft is warmer than that which would occur by adiabatic convection. Over a body of water, warm air aloft implies a temperature inversion, which usually leads to a strong water vapor gradient, hence microwave ducting. Studies have shown this parameter to correlate well with ducting conditions (R. Helvey, private conversations).

The discriminant analysis program, P7M of the UCLA BMDP statistical package (Dixon, 1977), was used to generate the classification functions for this correlation. The critical value of $\Delta\theta$ was found from the classification functions (see Sec. 3 of the main report). The results are summarized in the following tables and compared to the Δe method.

	Δe				
		Prefigurance (%)		Postagreement (%)	
Zone	Δe_c	Duct	Normal	Duct	Normal
1	10.4	78	77	79	76
2	7.8	66	84	75	78
3	6.3	53	91	72	80
4	5.6	40	93	69	81
5	5.1	32	97	72	85

	Δe				
		Prefigurance (%)		Postagreement (%)	
Zone	$\Delta\theta_c$	Duct	Normal	Duct	Normal
1	11.4	73	75	78	79
2	9.7	60	88	80	73
3	9.2	45	93	72	75
4	9.0	30	95	74	72
5	8.7	23	97	74	75

The prefigurance percentages for the Δe method and the $\Delta\theta$ method are similar, with the Δe method having the higher duct percentages. The only significant difference in postagreement percentages is in the normal category. The zonal variations of $\Delta\theta_c$ is not as much as that for Δe_c, indicating less dependence on climatology.

The following two tables compare the total percent correct and the difference between percentage of ducts forecasted and climatology ("obs." column is percentage of ducts observed, hence climatology).

Δe

Zone	Total % Correct		Obs.	Fcst.	Diff.
1	77		52	53	1
2	76		37	42	5
3	78		24	33	9
4	78		17	28	11
5	83		10	21	11

$\Delta\theta$

Zone	Total % Correct		Obs.	Fcst.	Diff.
1	74		53	56	3
2	75		35	46	11
3	75		22	37	15
4	72		14	35	21
5	73		12	31	19

The Δe method shows a general increase in total percent correct with latitude zone (see Section 4 for discussion); the $\Delta\theta$ shows only a minor fluctuation, with about a 74% overall average. The average for Δe_c is 78%, over 4% higher than the $\Delta\theta$ method.

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The last column in each of these two tables is the difference between observed and forecast number of ducts. A positive value for "difference" means that the method forecast more ducts than observed - a large positive value means a high false alarm rate. The $\Delta\theta$ method consistently had a higher false alarm rate than the Δe method. This high rate implies a procedure which is less responsive to climatology and, in many tactical applications, one that is misleading.

Summary

Both methods show good skill in assessing ducting conditions below the 850 mb level. The Δe method shows somewhat more response to change in ducting climatology, both in the Δe_c zonal variation and in the false alarm rate. The primary advantage to the Δe method is the requirement for only one level of data. In the foreseen application of the methods, large-scale model output fields will be used to calculate the value of the predictor. The surface values of temperature in some cases may be inaccurate due to the method of determining this parameter in the model.

APPENDIX B

Other Parameters Tested

The following additional variables and combinations of variables were tried using the multivariate discriminant analysis program:

$\Delta\theta$ - $\theta_{850} - \theta_s$; θ = potential temperature

TVS   -   surface virtual temperature

T850   -   temperature at 850 mb

TV850   -   virtual temperature at 850 mb

H850   -   height of 850 mb level

DESURF   - $(e_s - e)$ at the surface

DIFE   - $(\text{DESURG} - \Delta e)$

DIFTV   - $(\text{TVS} - \text{TV850})$

DT2   - $(\Delta\theta)^2$

The following table shows the three best combinations, along with the percentages for Δe.

Variable	Total Correct (%)	Prefigurance (%) Duct	Prefigurance (%) Normal	Postagreement Duct	Postagreement Normal
Δe	77	78	75	78	75
Δe T850	77	76	76	79	74
Δe T850 $\Delta\theta$	78	78	77	81	84
Δe TVS DIFF DTZ $\Delta\theta$	76	76	77	82	71

Postagreement percentages showed slight improvements for the set of three; no improvements in prefigurance or total correct percentages resulted. The other parameters tested yielded results which were slightly worse than the Δe percentages above.

In every case where the multivariate discriminant analysis program was given several variables (including Δe) to select, the first variable selected was always Δe. This means that Δe had the best discrimination characteristics of any of the variables.

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